The Application of L-band and C-band Radar Measurements to Monitoring Land Snow Cover

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ABSTRACT

L-band and C-band microwave radar observations can help to measure the properties of snow cover on land by providing information about the soil-snow boundary condition. In this theoretical study, we examine the sensitivities of microwave radar measurements to soil and snow characteristics, and we compare a simple model with previously published data. These data show that the thermal insulation provided by snow cover can have a powerful effect on the soil-snow boundary by altering the soil temperature and therefore changing the dielectric contrast.

INTRODUCTION

In this paper, we will examine some potential applications of low frequency microwave radar data to remote sensing of snow cover over land. We focus on the following low frequency microwave bands; L-band (1.28 GHz) and C-band (5.3 GHz). We also restrict our focus to snow parameter retrieval using radar backscatter measurements under dry snow conditions without significant contamination by trees or vegetation.

MODEL DESCRIPTION

The physical configuration is assumed to be a single layer of snow lying on frozen soil. The snow consists of ice particles in air with a characteristic mean density and mean snow grain radius. The incidence angle at the snow-air interface is 45° for all of the results in this paper. At L- and C-band, the backscattering cross-section (σ_0) is dominated by rough surface scattering from the frozen soil. Only at higher frequencies such as Ku-band does the volume scattering contribution in the snow become significant [1].

Although the snow layer does not directly contribute to the backscatter level, it does exert an indirect influence by altering the dielectric contrast at the soil-snow interface. The snow layer also refracts the incident beam towards a smaller incidence angle and reduces the backscattered intensity by widening the backscattered beam. We compute the dielectric constant of the snow layer using a theoretical calculation called the quasi-crystalline approximation with coherent potential (QCA-CP) which applies to dense random media. [2].

For the dielectric constant of frozen soil, we rely on experimental data supplied by Hallikainen [3]. These data are for silt-loam soil texture which gives results intermediate between sandy loam and silty clay. The data cover a range of frequencies, temperature, and soil water content which allows a debye-style mode fit and subsequent interpolation to desired parameters in this theoretical study [1].

SURFACE SCATTERING

For the purpose of computing the radar cross-section due to rough surface scattering ($\sigma_{0(surf)}$), we assume that the soil-snow interface is rough with gaussian statistics characterized by the rms height σ, and the correlation length l. Rough surface scattering at the snow-air interface, however, is not included because the low dielectric contrast results in a negligible backscatter contribution compared to the frozen soil surface. To compute $\sigma_{0(surf)}$ we use two rough surface scattering theories which apply to two different scattering regimes. For C-band, we use geometric optics with stationary phase (GO) which works when the surface is rough on the scale of a wavelength. For L-band, we use the small perturbation method (SPM) which works when the surface is smooth on the scale of a wavelength.

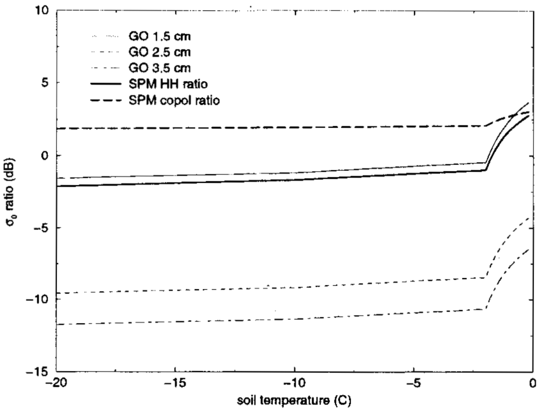

Figure 1: Time and polarization σ_0 ratios as a function of soil temperature for three different rms surface heights. l = 6.52 cm, 5.3 GHz - thin lines, 1.28 GHz - thick lines, snow density = 400 kg/m^3, snow temperature = -10 C, snow depth = 30 cm, snow grain mean radius = 1 mm, soil volumetric wetness = 0.25 cm^3/cm^3, incidence angle = 45°. Reference soil permittivity = 18 for time ratios.

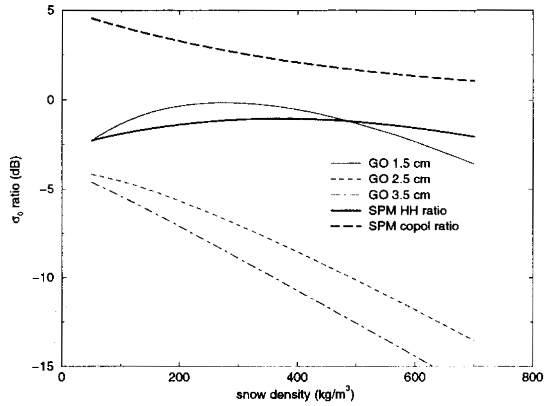

Figure 2: Time and polarization σ_0 ratios as a function of snow density for three different rms surface heights. Soil temperature = -3 C, other parameters match Fig. 1.

BACKSCATTERING RATIOS

In general, $\sigma_{0(surf)}$ is a function of both σ and l for both SPM and GO. These two unknowns can vary independent of snow conditions, thus introducing a source of error when we attempt to retrieve snow parameters. To reduce the dependence on surface roughness parameters, we form time and polarization ratios of σ_0. The co-polarized ratio is defined to be $\sigma_{0vv}/\sigma_{0hh}$. The SPM co-polarized ratio is independent of σ and l, and depends only on the incidence angle and the dielectric contrast at the soil-snow interface. In the GO regime, we define a time ratio between the σ_0 measured with snow to the σ_0 measured at the same location without snow, and assume that the surface roughness remains unchanged. The time ratio reduces the dependence on σ and l by dividing out their direct contribution, however, the change of incidence angle due to refraction into the snow maintains an exponential dependence on σ and l.

Figs. 1 and 2 show both the time ratio for GO and SPM, and the co-polarized ratio for SPM as a function of the snow and soil parameters that determine the dielectric contrast and the incidence angle shift. In Fig. 1 we see that increasing the soil temperature brings the time ratios closer to unity because the dielectric contrast between soil and snow is increased, bringing it closer to the reference contrast of 1:18. Most of the increase occurs at temperatures close to the freezing point because the liquid water content in the soil changes most rapidly here. We also see that the SPM co-polarized ratio is much less sensitive to changes of the soil dielectric constant than the time ratios are (1.2 dB vs. 5.3 dB). This difference occurs because the dielectric change affects both the numerator and denominator of the co-polarized ratio and is partially cancelled, while only the numerator of the time ratio is affected so there is no cancellation. Finally, we see that typical variations in σ can cause comparable or larger changes in the GO time ratios compared to the changes caused by soil temperature variation.

Fig. 2 shows the variation of the σ_0 ratios as a function of snow bottom density. The SPM co-polarized ratio now shows a stronger variation of 2.4 dB over the typical range of 100 to 500 kg/m^3. Snow density affects the co-polarized ratio more than soil dielectric changes because it affects the incidence angle as well as the surface response. The time ratios also show strong variation with snow density, but we still have the equally strong dependence on rough surface parameters. The co-polarized ratio is clearly more useful than the time ratios for tracking the snow density because it is contaminated by fewer additional variables. In some cases, however, we have to use time ratios because SPM does not apply, or multi-polarization data are not available.

COMPARISON WITH DATA

In this section, we examine aircraft C-band SAR data and associated ground truth collected and analyzed by Bernier and Fortin [4]. The ground truth data included the surface roughness parameters; σ = 2.48 cm and l = 6.52 cm. These values fall within the GO regime at C-band, and knowing them separate from the σ_0 measurements allows the use of time ratios without having to account for unknown surface roughness parameters. Using ground truth data in [4] we were able to fit a set of soil dielectric constants that generated the model time ratios shown in Fig. 3 [1]. The data are plotted against snow

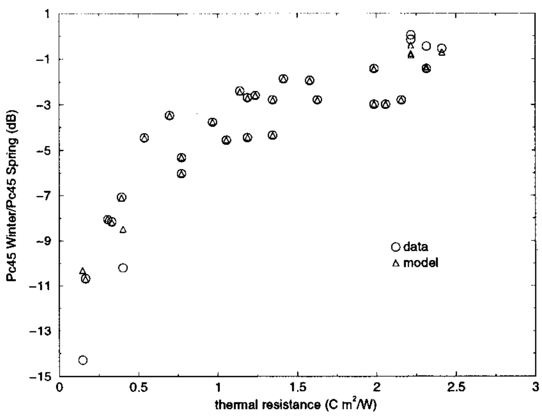

Figure 3: Comparison of data with model results generated using fitted soil temperatures. Soil volumetric water content = 0.55.

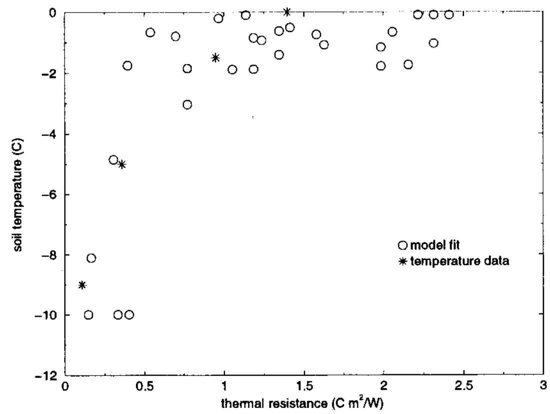

Figure 4: The fitted soil temperatures used to generate the model results in Fig. 3. Corresponding temperature measurements are plotted where available.

thermal resistance to match the appearance of Fig. 11 in [4].

Fig. 4 shows the model soil temperatures that correspond to the fitted soil dielectric constants along with the in-situ soil temperature data collected by Bernier and Fortin (see Fig. 8 in [4]). The fitted temperatures are contrained to lie between 0 C and -10 C to avoid unreasonable fits. This constraint could be relaxed if the soil water content and texture were allowed to vary, however, no data is available to constrain these parameters, so the fit was left as is. The model temperatures are consistent with the available measurements, and most of the points are a few degrees C below 0 which is typical for frozen soil. These results indicate that the physical model and the scattering model are consistent with the data, and that they capture the important parameters and scattering processes.

CONCLUSIONS

Scattering and emission at L- and C-band are dominated by rough surface scattering from the soil-snow interface for typical dry snow conditions. Although L- and C-band microwave observations are not directly sensitive to snow depth, they can make an important contribution by measuring the dielectric contrast at the soil-snow interface. This reduces the number of unknowns in any corresponding higher frequency observations which are also affected by the lower boundary condition.

As pointed out in [4], the thermal insulation provided by snow cover can have a powerful effect on the soil-snow interface by altering the soil temperature and therefore changing the dielectric contrast. In cases where the insulation effect is strong, it may appear that snow depth is directly affecting low frequency microwave backscattering even though in reality it is the dielectric constant of the soil which is changing. Because the microwave response of snow cover is so sensitive to the conditions of the underlying frozen soil, it is important for future ground truth campaigns that measure snow conditions to also collect data on the temperature, water content, and texture of the soil. This will help to separate the volume scattering effects in the snow from the effects of surface scattering at the soil-snow interface.

ACKNOWLEDGMENTS

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REFERENCES

[1] R. D. West, "Potential applications of 1-5 GHz radar backscatter measurements of seasonal land snow cover," Radio Science, in press, 2000.

[2] L. Tsang, C. Mandt, and K. Ding, "Monte Carlo simulations of extinction rate of dense media with randomly distributed dielectric spheres based on solution of Maxwell's equations," Optics Letters, pp. 314-316, 1992.

[3] M. Hallikainen, F. T. Ulaby, M. C. Dobson, and M. El-Rayes, "Dielectric measurements of soils in the 3- to 37-GHz band between -50 C and 23 C," Proceedings of IGARSS 1984 Symposium, Strasbourg, pp. 163-168, Aug 1984.

[4] M. Bernier and J. Fortin, "The potential of times series of C-band SAR data to monitor dry and shallow snow cover," IEEE Trans. on GeoScience and Remote Sensing, vol. 36, no. 1, pp. 226-243, Jan 1998.